# Solar Resource Assessment Methodology for Bhutan

## Introduction

This document describes development of detailed high-resolution (10-km) solar resource maps for Bhutan. These maps were created by the United States Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) and the Atmospheric Sciences Research Center (ASRC) at the State University of New York (SUNY)/Albany (USA), in collaboration with the Department of Energy, Ministry of Economic Affairs, and Royal Government of Bhutan. The project is sponsored by the United States Agency for International Development's (USAID) South Asia Regional Initiative for Energy Cooperation and Development (SARI/Energy).

The solar resource assessment conducted in this study combined analytical, numerical, and empirical methods. The sections below describe the data sets and analytical methods used to develop the solar data and comparisons of the data products with solar ground data sources.

## Solar Resource Assessment Methodology

The ASRC has developed a large-area solar resource assessment methodology using the visible image channel from geostationary weather satellites [1]. During the past 10 years, the ASRC has developed and tested their methodology using the Geostationary Operational Environmental Satellites (GOES), which are launched and maintained by the U.S. National Oceanic and Atmospheric Administration (NOAA). Once placed in orbit, these satellites remain at a fixed point above the Earth's surface over the equator. During the past 25 years, a series of GOES satellites have been launched to cover the entire Western Hemisphere. Among other data sets, these satellites collect high-resolution (~1-km) visible-channel images of the entire hemispheric field of view every 30 minutes.

The ASRC method uses a semiempirical approach to convert visible channel imagery to hourly estimates of solar resources on a 10-km grid. Solar resource estimates include both direct normal insolation (DNI) and global horizontal insolation (GHI). This methodology has been widely used for solar resource assessments in the Western Hemisphere. For example, the model was recently used to produce the 1998-2005 high-resolution data distributed as part of the U.S. National Solar Resource Data Base [2]. Researchers at SUNY and NREL used the model to develop a solar map of Oaxaca, Mexico, for USAID [3], and maps of solar resources in Central America for the United Nations Environment Programme (UNEP) Solar and Wind Energy Resource Assessment (SWERA) project [4]. The model has been extensively validated for these Western Hemisphere applications [e.g., 2].

To estimate solar resources in the Eastern Hemisphere, SUNY adapted the model to use the European Meteosat 5 and 7 geostationary satellites, which are positioned at the longitude of central Asia ($57.5^{o}$ east). This revised model was first used to develop solar resource assessments in Afghanistan and Pakistan [5] and was recently used to estimate solar resources in northwest India. SUNY and NREL researchers evaluated the model output for India against surface solar measurement data supplied by the Indian Meteorological Department (IMD), NASA Surface meteorology and Solar Energy (SSE) data [6], and output from NREL's Climatological Solar Radiation (CSR) model [7].

The results of the ground-truthing evaluation for northwest India show that in addition to markedly different climatic conditions, there are small but significant differences between the treatment of GOES and Meteosat images, which could affect the accuracy of the SUNY model. These include a different spectral window for the visible channel, and a different processing of the archived images.

In May 2009, analysts will present a paper on the validation of the SUNY algorithm against four ground-truth stations from the IMD solar radiation network located within or near the province of Rajasthan, India. It will be published in the proceedings of the Annual National Solar Conference 2009, Buffalo, New York, May 13-16, 2009 [9]. The stations include Bhopal, Jaipur, New Delhi, and Jaisalmer. Their results show that there may be a problem with estimates of DNI from GHI over northwest India. This may be a combination of quantitative uncertainty about the levels of aerosol optical depth, which vary widely when estimated by different techniques and/or qualitative uncertainty in the use of aerosol and turbidity data to estimate direct normal insolation. The last may be due to a fundamental difference in the types of aerosols prevalent in South Asia.

**Comparison of SUNY model output with ground data from Bhutan**

For the Bhutan study, estimates of GHI were available from 12 measurement stations over several years. However, most of the data was not used due to missing or irregular data. The two stations with the most complete and internally consistent results were Thimphu and Punakha, which were compared with the modeled output. Figure 1 shows very good agreement for both stations in 2007, although the alignment for both stations was much worse in 2006. Additional information on the solar measurement equipment – including calibration records and site characteristics – was unavailable, so the analysis does not include a more detailed comparison of measured and modeled data.

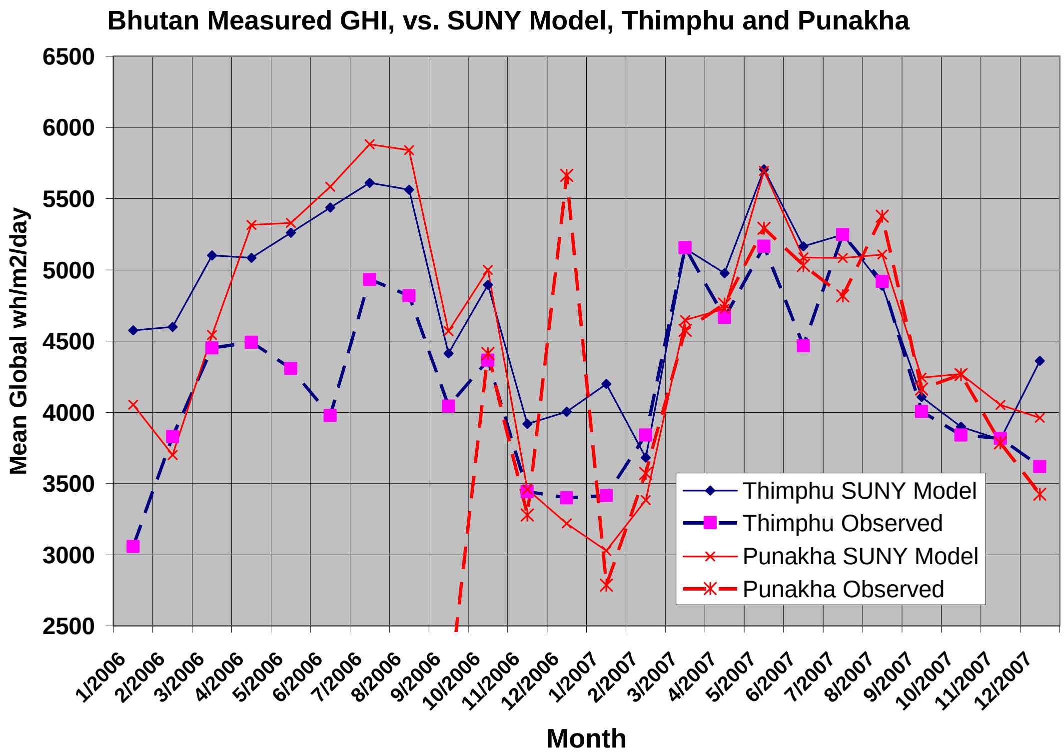


**Figure 1.** Comparison of measured GHI with SUNY satellite estimate, monthly mean values for years 2006 and 2007, for two stations (Punakha and Thimphu).

## Conclusions

The solar resource data and maps developed for Bhutan describe the potential for widespread application of flat-plate solar collectors across this region. Comparisons of the SUNY modeling output of GHI with ground data and other available data sets show good agreement, which lends confidence to the satellite-derived data sources.

Generally, DNI values in Bhutan are fairly low (2.5 – 4.0 kWh/m$^2$-Day), thus any prospects for development of concentrating solar power (CSP) in Bhutan are marginal at best. There may be a few high-altitude areas of northern Bhutan that have higher average DNI; however, before these are more closely explored, any potential discrepancies in the DNI data should be examined further.

## References


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(2) George, R., Wilcox, S.; Anderberg, M.; and Perez, R. (2007). “National Solar Radiation Database (NSRDB) - 10 Km Gridded Hourly Solar Database.” Proceedings of Solar 2007, Cleveland, OH, Published by the American Solar Energy Society.

(3) These maps can be found at http://www.nrel.gov/applying_technologies/maps_atlases_inter_res.html.
(4) These maps can be found at http://unep.swera.net
(5) Maps and documentation for Afghanistan can be found at http://www.nrel.gov/applying_technologies/ra_afghanistan.html; maps and documentation for Pakistan can be found at http://www.nrel.gov/applying_technologies/ra_pakistan.html
(6) NASA Surface meteorology and Solar Energy Data Set http://eosweb.larc.nasa.gov/sse/RETScreen/
(7) Maxwell, E. L.; George, R.L.; and Wilcox, S.M. (1998). "A Climatological Solar Radiation Model." Proceedings of Annual Solar Conference 1998, Albuquerque, NM. Published by the American Solar Energy Society, pp. 505-510.
(8) ISCCP - International Satellite Cloud Climatology Project http://isccp.giss.nasa.gov/
(9) Richard Perez et al., validation of the SUNY Satellite Model in a Meteosat Environment, to be presented at Solar 2009, Buffalo, NY, 13-16 May 2009, to be published by the American Solar Energy Society.